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EDDY-CURRENT INSPECTION OF SHUTTLE HEAT EXCHANGER TUBE WELDS*

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ABSTRACT

The Space Shuttle Main Engine is inspected during manufacture, after each test firing, and as part of refurbishment between missions. The LOX heat exchanger has four tubing welds in locations that are difficult to reach and inspect. The most difficult to access is located approximately 30.6 in. (0.78 m) from the inlet, through tubing 0.190 in. (4.83 mm) ID, past a 90 degree, 0.69 in. (18 mm) radius bend, and approximately halfway around a loop 16.5 in. (42 cm) diameter. We designed a multiple property test using computer-aided engineering software written, at ORNL earlier, that modeled the tube and probe and enabled simulation of instrument response in the inspection environment. Design parameters were optimized for a single-winding, single-layer "pancake" coil. The necessary sensitivity to small defects can be achieved within the limits imposed by material variations. The probe contains an array of eight coils. Four coils each are mounted 90 degrees apart on the equators of two plastic spheres joined at their poles by a straight section. The two four-coil arrays are offset 45 degrees, so that as the probe passes through the tube, one coil covers each 45 degree segment of the wall circumference. Lift-off up to 0.008 in. (0.2 mm) is electronically compensated by corrections developed in the design, so there is no requirement to maintain intimate contact between the probe and the tube wall.

Experimental multifrequency measurements performed on tubing weld specimens supplied by Rockwell Rocketdyne Division indicated the presence of ferrite in the welds, which likely accounts for anomalous results observed in single-frequency eddy-current tests. In addition, there was a weld pedestal that ranged up to 0.004 in. (0.10-mm) in the tube samples tested. This pedestal tended to produce signals that were in a direction opposite to that of the defect signals.

The system response to multiple discrete frequencies was simulated by computing the response to each independently and combining the results. The presence of ferrite in the welds suggested the use of pulse excitation to reduce sensitivity to variations in permeability. Final system tests demonstrated that a 0.005 in. (0.13 mm) deep defect could be detected with the array probe, using the three-frequency eddy-current instrument driving the multiplexer coils. A 0.003 in. (0.08 mm) deep defect and a 0.006 in. (0.15 mm)

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deep defect at the welds were detected in the split tube samples. A single coil was driven by the impedance analyzer at three and then six frequencies. The signal to noise ratio was best at the six-frequency test, which indicates that the pulse test, with its higher frequency content, will be superior to the three-frequency test. However, the pulsed measurements were not made due to time constraints.

INTRODUCTION

Background

The present method for manufacturing inspection the of welds in heat exchanger tubing and combustion chamber injection posts in the Space Shuttle Main Engine (SSME) uses single-frequency eddy currents. There were difficulties with signal interpretation and probe clearances through accesses when using this method. Eddy-current tests have not been applied to the inservice inspection of these components.

The Oak Ridge National Laboratory has expertise in multiple-frequency and pulse excited eddy-current inspection technology.^{1,2} The incentive for use of multiple-frequency techniques is the need to achieve accurate detection and sizing of weld flaws while rejecting or discriminating against the effects of variations in other properties, such as tubing wall thickness or probe liftoff. Single-frequency systems respond to several different property variations, and in many cases cannot distinguish the anomalous test indications from flaws, causing false positives.

Pulse Eddy-current (PEC) technology effectively examines the part with many frequencies.^{3,4} Measurements of the pulse shape required for analyses, however, can be accomplished with simpler, more reliable, and less expensive instrumentation than that required for multiple discrete frequencies. If the pulses are large enough, they saturate any permeability changes in the material and reduce their effect on the test. Nevertheless, PEC was a later development because the analysis leading to signal processing algorithms was more difficult.

Problem

A representation of the heat exchanger along with the three welds that were proposed for technique development are shown in Figure 1. The welds are listed below:

- (1) the LOX heat exchanger Primary Tube-Bifurcation Joint Transition (RS008812 -#3 in Figure 1);
- (2) the LOX Heat Exchanger Secondary Tube-Bifurcation Joint (so-called "Baby Pants") welds (RS008812 -#1 and #2 in Figure 1); and
- (3) the Main Combustion Chamber Injection Posts which are straight tubes in the same size range with similar welds.

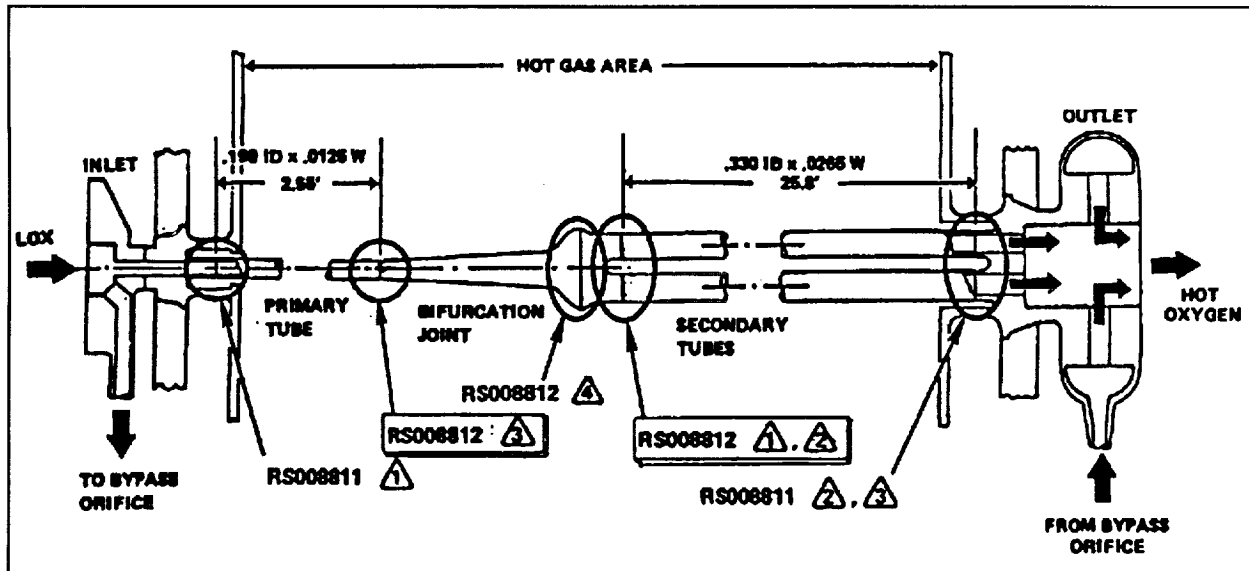


Figure 1 Space Shuttle Main Engine Heat Exchanger Tube Assembly

The second weld from the inlet (RS008812 -#3 in Figure 1) was judged the most difficult and was selected for demonstration. Weld #3 joins the 0.190 in. ID x 0.0125 in. wall inlet tubing to the expansion tubing. It is located approximately 30 in. downstream of the inlet flange, but the probe must negotiate a sharp (0.69 in. radius) bend to reach the weld. Alternate access is from the outlet port, but from that direction, the probe must traverse approximately 26 ft. of 0.330 in. ID tubing wound into a cylindrical coil approximately 16 in. diameter.

The target flaw for detection is 0.003-in.-deep x 0.075-in.-long. Depth is measured in the radial direction; length is measured circumferentially. Flaws of this general shape may result from lack of penetration in the original weld or cracks induced by forming or low cycle fatigue during service.

Capability is desired for manufacturing inspection, inservice inspection following ground test engine firing, and inspection during refurbishment between shuttle flights.

Objective

This goal of this project was to develop the system necessary to demonstrate in the laboratory that an eddy-current system can inspect the tubes and welds described above, screening for the existence of flaws equal in size to, or larger than, the target flaw. The laboratory system was to include the probe necessary to traverse the tubing, the electronics to drive (i.e., electrically excite) the probe and receive and process signals from it, a data display, data recording and playback devices, and microprocessor software or firmware necessary to operate the system.

APPROACH

Eddy-Current Database Review and Preliminary Estimates

ORNL has an extensive library of software that accomplishes for eddy-current testing what is now commonly called "computer aided engineering" (CAE). This software allows the insertion of various parameter values for a complete test environment, including a simulated specimen, probe coil, and instrument. These parameters can be systematically varied to produce an optimized coil design and a set of optimized system operating parameters (e.g., operating frequencies) for a specified range of specimen properties.

From the results of years of simulations for many system designs, a large database has been developed. This database provides a ready reference for the rapid estimation of new problems and a checkpoint for new results as they are computed. Approximate curves and "rules of thumb" have been developed. These indicated that, for defect detection in this size tubing and with these conductivity values, a coil mean radius of about 0.025 in. and an operating frequency of 1.5 MHz were suitable. With these parameters, a defect about 20% of the wall thickness should be detectable.

Probe Configuration

Rocketdyne previously developed a fluid pumping system, freon filled, capable of propelling a string of spherical beads to pull a cable through the finished heat exchanger. Therefore, we looked at bead shaped carriers for the probe coils that could be adapted for use with the existing freon drive system. However, for the demonstration system, a rigid dumbbell shaped carrier (two spheres connected by a straight section) was connected to a stiff cable that could be pushed by hand through the inlet entry tube. Figure 2 shows the probe form inside the bend in the tube. The coils are molded to the spherical shape of the probe form and mounted in the recesses provided.

The freon pumping system offers limited restraint against torques and appropriate connections can prevent continuous rotation of the beaded inspection probe. To accomplish inspection of the entire weld circumference, probe coils were mounted on two successive beads in a string with an angular offset to create a circular array, so that when the complete string has passed the weld, the entire circumference will have been inspected. The probe contains an array of eight coils. Four coils each are mounted 90 degrees apart on the equators of the two spheres, in patterns which are offset 45 degrees. The diameter of the spheres was chosen to allow passage around the curve in the tubing and through the weld sections of the tube. The shape of the probe allows the probe to pass the small 90 degree entry bend without flexing the straight section.

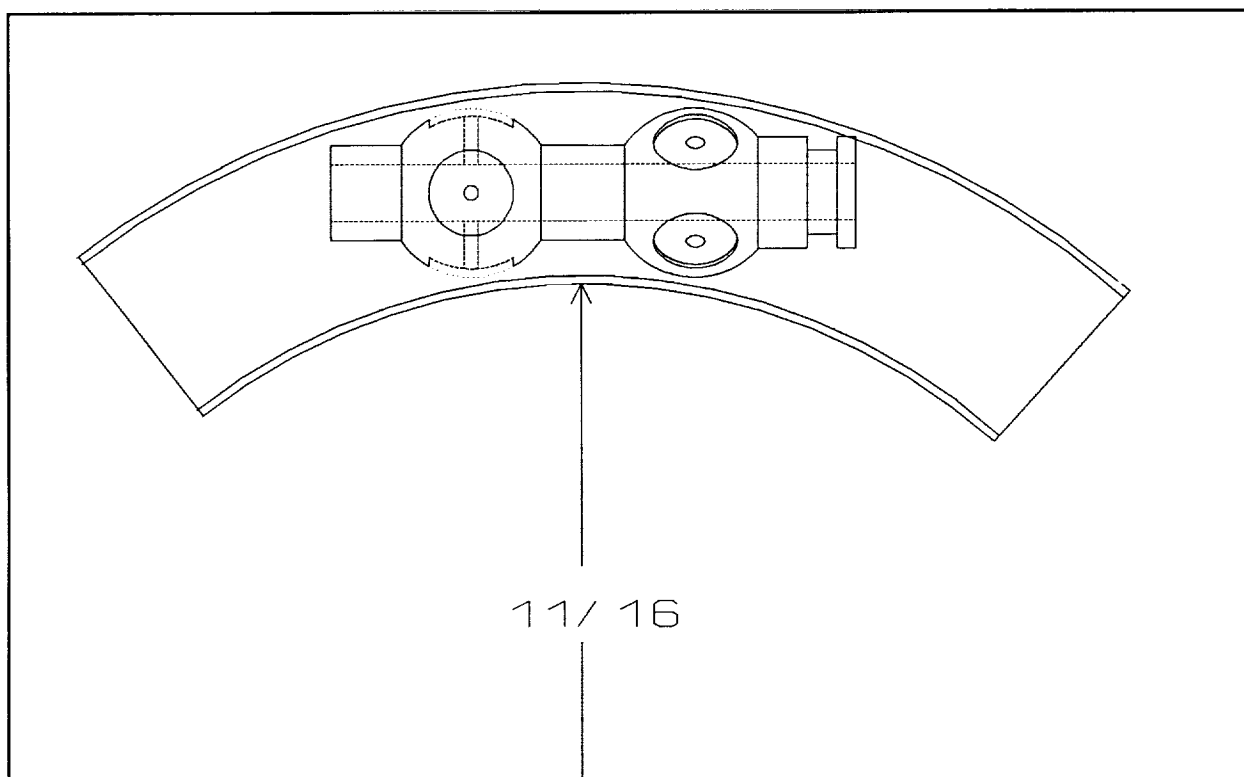


Figure 2 Probe form inside the small radius bend of the heat exchanger tube

Coil Design

Dimensions and electrical parameters for individual probe coils were estimated from reference data derived from the results of previous computer simulations, as described above. However, because of the introduction of variables not considered in the preliminary estimate, confirmatory simulation by computer was considered to be a prudent precaution. Although the coils in the holder have spherical contours, the approximation of a flat pancake coil was the best available. The curvature of the coil will add some liftoff to parts of the coil. The effect of this curvature can be approximated by making the liftoff for the flat coil case equal to that of the curved coil, measured at the mean radius of the curved coil.

System Options and Configuration

Probes using coil arrays similar to that described above have previously been used with single-channel instrumentation by including a multiplexer to switch connections to the instrument in a programmed sequence. Sufficient switching speed can be achieved to compensate for continuous probe motion while ensuring adequate surface coverage. Single-channel instrumentation is significantly less costly and awkward to operate than multichannel.

Three instrument packages were considered for evaluation and laboratory demonstration:

(1) A Hewlett-Packard Model 4192A Low Frequency Impedance Analyzer, controlled through a General Purpose Interface Bus (GPIB, IEEE-488 standard) by an existing laboratory computer (IBM System-9000 or PC AT);

(2) A modular multifrequency eddy-current instrument with phase-sensing capability, designed and built by ORNL, controlled by GPIB with the laboratory computer; and

(3) A pulse-excited eddy-current instrument of initially unspecified configuration.

RESULTS AND DISCUSSION

Functional System Design, Modeling, and Simulation

A modeling program initially written and used for flat plates was modified to accommodate the design of a so-called "pancake" coil, which is a low profile cylindrical coil with its axis normal to the surface against which it is used. The probe design incorporates these coils with their axes coincident with radii of the spherical beads, placing the major plane tangent to the sphere and approximately parallel to a tangent of the inside tube wall.

Early results from the simulations (which included full instrument response and data processing) indicated that a pulse instrument would be superior to the multifrequency instrument for this application. The multifrequency instrument and the pulsed instrument both give similar responses and collect data that contain similar information with the following exception. The multiple frequency inspection was more affected by the permeability variations observed in the weld region. In cases where the tube wall material has a large permeability value, the electromagnetic wave generated by the probe will not penetrate the material. Thus, the outer surface of the material cannot be inspected. However, with high power pulses the material can be saturated and inspected in a manner similar to that of normal eddy-current tests. Although the permeability of the weld is not great enough to shield the outer part of the tube, it does cause a variation in the signal which must be compensated for and which increases both the overall noise and the difficulty of the measurement.

Coil Design

Coil design simulations were carried out for the pancake coil. The properties of the test were varied over the ranges shown in Table 1. Instrument readings were computed for a total of 500 different combinations of the properties. A least-squares fit relating the readings to the properties yielded a set of linear coefficients. The fitting coefficients are linear but can be multiplied by nonlinear combinations of the readings. The rms error in the measurement of a particular property for both the fit and instrument drifts was calculated for the entire range of

variation of the properties shown in Table 1. The instrument readings were computed at six different frequencies (0.2, 0.5, 1, 2, 5, and 10 MHz), and a pattern of nonlinear readings was fitted to the properties for each combination of frequencies taken three at a time. The frequency and reading combination that gives the least error was chosen. This error varies as the coil size (mean radius) is varied. The results of the error calculations for the pancake coil are shown in Table 2.

It appears that the optimum mean coil radius is 0.0325 in. and that the minimum error remains 0.0006 in. between 0.030 and 0.035 in. mean radius. Typical inner and outer radii would be 0.8 and 1.2 times this value. The variation in the material will generally limit the detectability to a defect depth equal to about 5 to 10% of the tube wall thickness. By increasing the mean radius slightly, to 0.035 in., a larger gauge wire can be used which will further ease the fabrication problems and give better coverage with no sacrifice in sensitivity. With such a coil size, an array of eight coils spaced at 45 degree angular offsets will ensure sufficient coverage to prevent any circumferentially oriented defects from escaping detection.

Although our discussion has centered on the detection of defects, any of the other property variations, such as liftoff (and therefore tube inner diameter), wall thickness, conductivity, and permeability can also be determined. These properties can be computed from the same readings that the defect sizes are, but using a different set of coefficients. Other properties can be discriminated against, such as the variations caused by tube supports. The only requirement is that the property variations be present in an adequate number in the calculated or experimental readings. We can then determine these properties to the degree of accuracy that we know their input data values.

Table 1 Range of property variations for the NASA heat exchanger problem.

Defect depth	0 - 6 mils
Wall thickness	13 - 17 mils
Resistivity micro-ohm cm	70 - 90
Lift-off	0 - 8 mils

Table 2 Defect measurement error (in.) due to the property variations.

Coil Mean Radius	Defect Size Error
0.020	0.00088
0.025	0.00076
0.030	0.00062
0.0325	0.00062
0.035	0.00062
0.040	0.00092

Instrument Selection

Initial experimental work was done with the HP Impedance Analyzer, using a single coil mounted on a holder. The impedance analyzer was stepped from frequency to frequency using signals from a computer transmitted over the IEEE-488 bus. Although the instrument is rather slow (making only about one reading per second), it is adequate for the low-speed test design readings. A bridge circuit with a differential amplifier was added so that the difference between a reference coil in air and the test coil on the sample could be measured.

Three of the weld samples from Rocketdyne were split so that the liftoff could be varied. The samples were placed in a mechanical positioner that was also controlled over the bus. The samples were scanned at 0.005 in. intervals and the liftoff was varied from 0.0 to 0.008 in. in 0.002 in. increments. About 50 points were taken in the free tube and in the weld reading from each of the six samples. A "shaped" defect value was used for the 0.003 and 0.006 in. defects that were in two of the samples. The "shaped" value was equal to the defect depth when the coil was directly over the defect and decreased as the coil moved away from the defect. This decrease matched the natural response of this type of coil to this type of defect, and is similar to the defect shapes shown in Figure 3.

Measurements were made at frequencies of 200 KHz, 500 KHz, 1 MHz, 2 MHz, 3 MHz, and 4 MHz. Due to limitations on the frequency response of the bridge amplifier, we used 3 MHz and 4 MHz rather than the computed frequencies of 5 MHz and 10 MHz. Fitting coefficients were obtained for both three and six frequencies using these readings. The best three-frequency fit showed an error of 0.0014 in., while the six-frequency error was 0.0013 in. It should be recognized that, although the experimental readings did include the permeability variation, they did not include nearly as many property variations (particularly the defect variations) as the computed readings. In particular, we should have had defect standards with defects in the heat-affected zone and in the bare tubing, as well as in the center of the weld.

Since only two weld defects were available, these were the only ones used. The samples were difficult to align properly due to the small size of both the coil and the samples. A small error in the axial position of the defect could result in a very poor fit. Several attempts were required before the samples were adequately aligned and good fits were obtained. Figures 3 and 4 illustrate the scans of the defects using a three-frequency fit.

These scans are made at five different liftoff values, and plotted sequentially. Although these defects look rather good in the figures, the noise was also high. Scans were also made using a six-frequency fit, and in general, the six-frequency fit was better and less noisy than the three-frequency fit. This suggests that

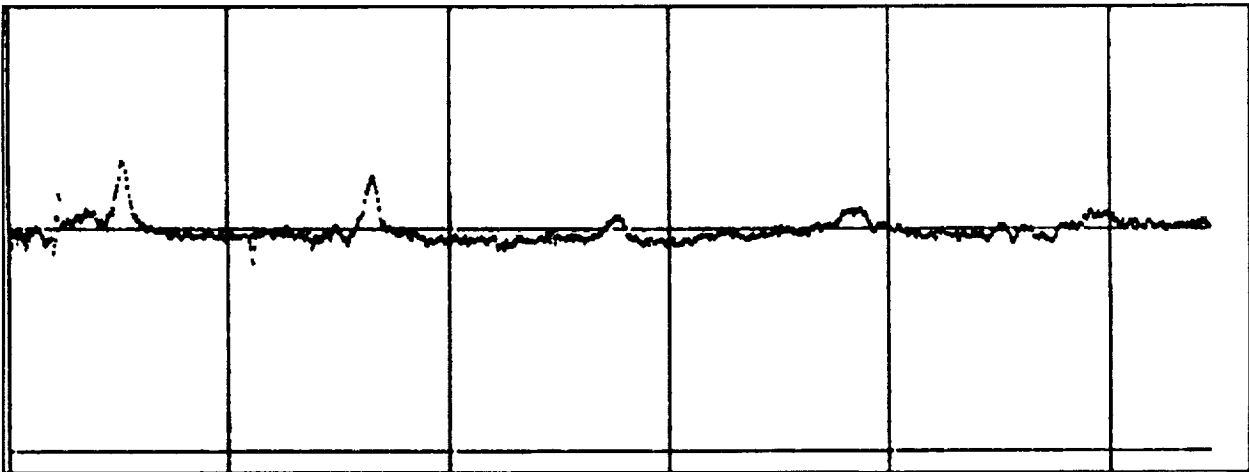


Figure 3 Scan of 3 mil deep defect for five lift-off values

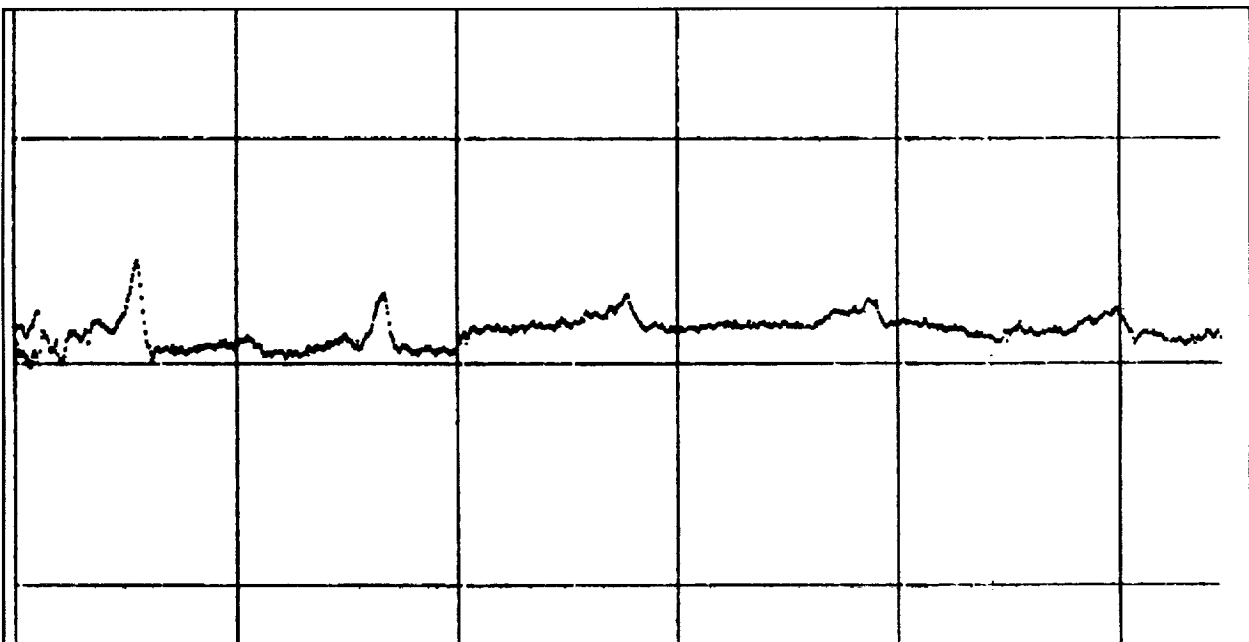


Figure 4 Scan of 6 mil defect for five values of lift-off

the pulse instrument, with its greater frequency content, would give better data.

Neither fit works well for the entire 0.008 in. liftoff range, but scans of the tube samples available showed that none of the tubes would allow more than about 0.004 in. of liftoff. The liftoff of the probe was difficult to set exactly due to the small size of the coils and the irregularity of the samples. The liftoff was quite likely greater than the value assumed for these measurements. Additional fits were run for smaller liftoff ranges and the fits improved as the liftoff range decreased.

The measurements were repeated using the three-frequency instrument, as shown in Figure 5. This instrument consists of

three independent oscillators to generate the three frequencies. These frequencies are mixed and then fed to a power amplifier and through a dropping resistor to a coil. The coil signal, which is modified by the interaction with the eddy currents in the conductor, is then fed to three bandpass amplifiers that separate the individual frequencies. The magnitude and phase of each frequency is measured, digitized, and then fed to the controlling computer. Measurements can be made with this instrument about 40 times faster than with the impedance analyzer, and the results, although similar, are not quite as good. This is probably due to a small sample misalignment.

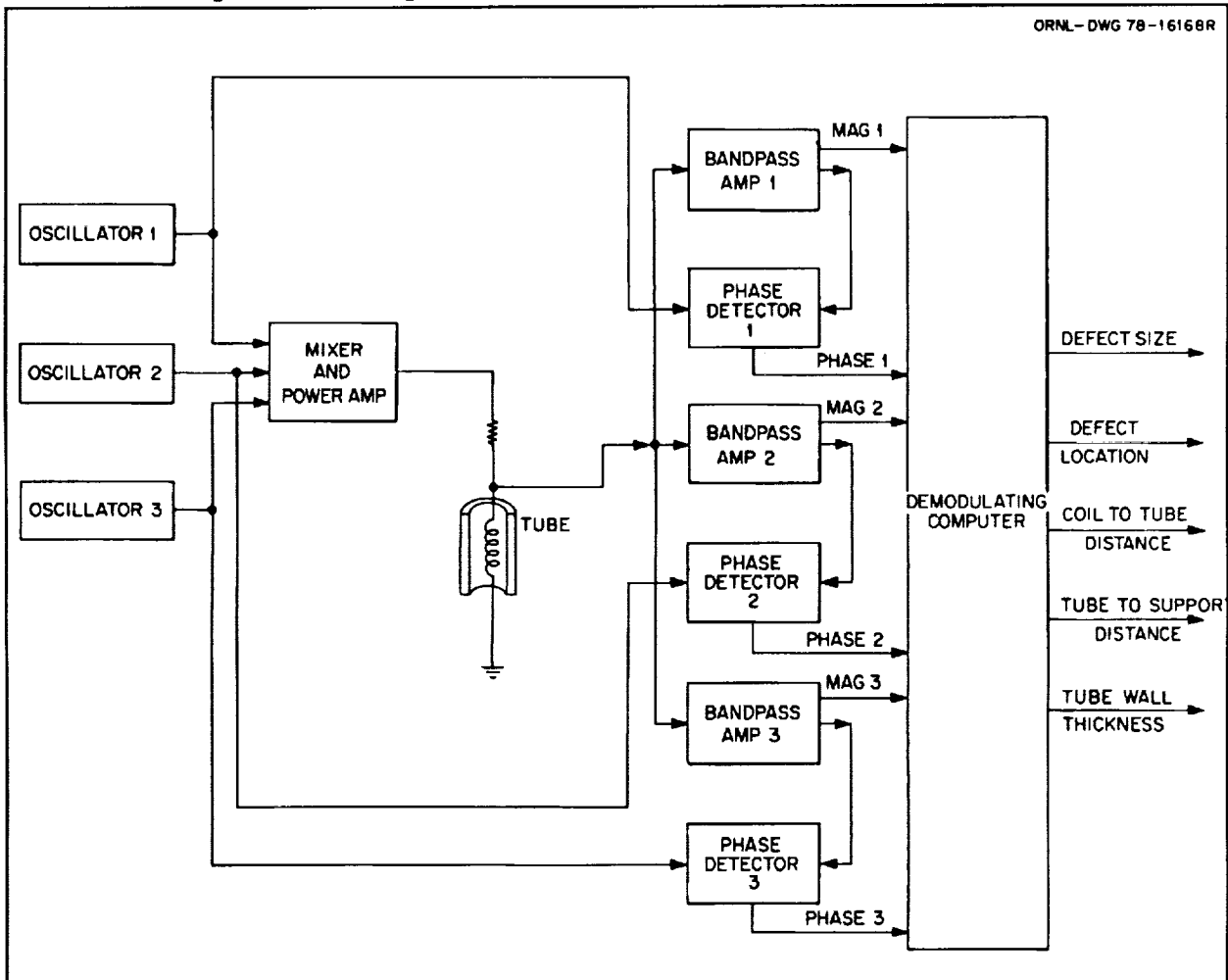


Figure 5 Block diagram of a three frequency instrument

Finally, measurements were made using the array coil. The fitting on the six samples was repeated first using a single coil in the array. The array probe was electrically connected as shown in Figure 6. An unbalanced bridge circuit is formed between the selected coil and the reference coil, and the multiplexer, on signals from the three-frequency instrument, steps from one coil to the next. A program in the microcomputer of the instrument controls the multiplexer module.

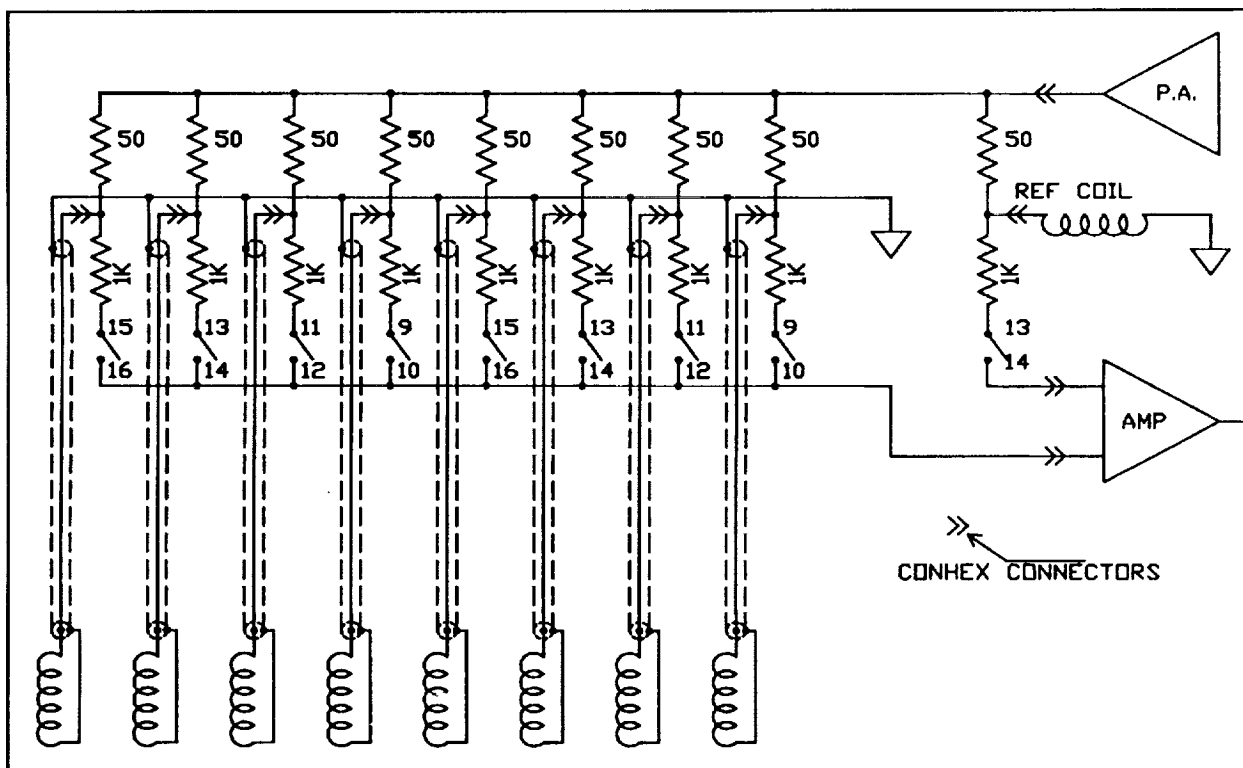


Figure 6 Electrical connections for the eight-coil multiplexed array probe.

The fitting coefficients were calculated for only one coil in the array, and an offset function was calculated from the value of each of the coils in air. This was done because it is very difficult to wind the coils exactly the same, particularly when the coils are this small. The offset is a function of the coil inductance, and is needed to electronically "balance" the bridge with the coil in air. This correction was then applied to each of the coil readings as the multiplexer stepped from coil to coil. This technique saves the time and effort that would be required to run a complete training set on each coil in the array, compute the fitting coefficients, and store a separate set for each coil in the array. A better match would be obtained if a gain correction were also applied. However, to do this requires an additional standard which was not available at the time.

Figure 7 illustrates the scan of an independent tube sample (not one of the standards used to obtain the fitting coefficients). Each trace is from a different coil in the array, and the lowermost coil is the only one positioned to pass over the defects. The first defect is 0.005-in. deep, and the second is 0.007-in. deep. The rising signal at the end of the scan for the upper four coils is from the tube end. The data from these coils are offset by about 0.240 in. from the first four coils (see Figure 2). In plots made on the CRT this offset is corrected so that data from the

coils at the same position across the screen represent the same axial location on the tube.

Although the readings from the multiple-frequency instrument were much faster than the impedance analyzer, they are still too slow to allow the weld to be scanned and insure that there is no data skip due to "probe pop." This occurs when the probe hangs on the weld, the cable stretches and then the probe pulls loose. The probe can then move at a rate of 0.5 m/s for a short time, and the examination of a short length of tubing will be skipped. Unfortunately, this is the section where a defect is likely to occur. The maximum data rate for the three-frequency instrument is about 40 readings per second, but about 32,000 readings per second are needed to insure that there are no skips when the tube is inspected at 0.5 m/s. The three-frequency instrument uses an 8080 based microcomputer with an IEEE-488 bus, which has been named the COMP9B computer.⁵ Both the 8080 microcomputer and the IEEE-488 bus limit the inspection speed.

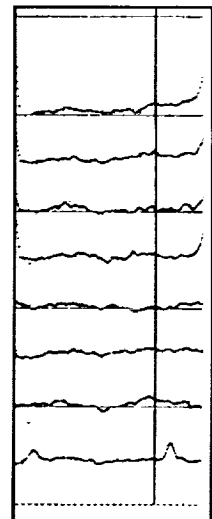


Figure 7
Scan using
an array
probe.

A block diagram of the pulsed instrument we developed is shown in Figure 8.⁴ This instrument generates a pulse that drives a coil. The resulting electromagnetic wave is of sufficient amplitude to saturate any ferromagnetic material near the probe and also generates eddy currents in the sample. This signal can be detected either by a sampling coil or directly using a dropping resistor in series with the primary coil. The signal amplitude as a function of time can be measured, either on the turn-on portion of the signal or the turn-off portion of the signal when a single coil is used. The value of this signal can be offset and amplified at each time interval. This is necessary since the total pulse response may be quite large and the important information may be a small part of the signal. The amplitude of the signal is sampled using a track-and-hold amplifier, digitized, and sent to a computer. This amplitude can be used as a reading to determine the sample properties in a manner similar to that employed for multiple-frequency measurements.

Although the drawing, in the interest of simplicity, includes the components for four channels of data, the instrument actually has eight data channels. The instrument can be set up using signals transmitted over the bus, so that no manual adjustments are necessary. These adjustments include the pulse amplitude, on time and off time, the gain and offset of each amplifier, and the offset of bandpass filter amplifiers (not shown in the block diagram). In addition the time at which each sample is made can be controlled independently.

Since the instrument setup is controlled by a computer program, a large reading pattern can be programmed and then the ones that best fit the sample properties can be selected. In addition, if a new set of properties is encountered as the tube is being scanned, the

The diagram illustrates a four-channel computerized spectrometer system. At the top, a **COMPUTER** is connected to a **PULSER**. The **PULSER** is connected to a **SAMPLE** and a **SAT. COIL** (saturation coil). The **SAMPLE** is connected to a **DET. COIL** (detector coil). The **DET. COIL** is connected to a **BUFFER AMP.** (buffer amplifier). The **BUFFER AMP.** is connected to a **COMPUTER**. The **COMPUTER** is also connected to four **A-D CONVERTER** (analog-to-digital converter) blocks. Each **A-D CONVERTER** is connected to a **TRACK AND HOLD** block. Each **TRACK AND HOLD** block is connected to a **GAIN AND OFFSET** block. The **GAIN AND OFFSET** blocks are connected to the **COMPUTER**. The **COMPUTER** is also connected to the **PULSER**.

Figure 8 Block diagram of pulsed eddy-current instrument along with a saturating pulse

119

The pulse power could be increased to insure saturation, and decreased again to allow probe cooling after the region was passed.

Pulsed Instrument Design

Preliminary design of a pulsed instrument that resides on a PC-AT bus was completed. A block diagram for this instrument is shown in Figure 9. This eddy-current instrument can transfer data at a rate of 400,000 bytes per second, compared to a rate of 1000 bytes per second for the 8080 based COMP9B computer. The pulsed instrument could also pulse one coil at a time and read all the coils in parallel, rather than driving all the coils in parallel and multiplexing the output as the three-frequency instrument does. In addition, less heat would be generated in the probe than would result if all the coils were pulsed every time. The time required for the switching transients to settle out would be eliminated. The analog-to-digital convertors would have to be replaced with faster models, but these are readily available.

The instrument is based on the design of the pulsed instrument described in the previous paragraph, but has been modified to fit on two standard PC-AT bus cards. Bus interface and control circuits were designed using programmable array logic (PAL) chips. These circuits are faster and more compact than comparable discrete logic chips. Tests of the interface chips and some of the pulsed circuit on the bus indicate that some further modification of the circuits will be necessary before an optimum configuration is achievable. However, a transfer of 16 bits of information at a rate of 200 KHz was demonstrated. By using a PC-AT as the controller for the pulsed instrument, we can significantly reduce the cost while increasing access to a large amount of support software. Although the present "test bed" utilizes a 16 bit 80286 microcomputer, a 32 bit 80386 based system should be faster and cost very little more.

CONCLUSIONS

Computerized designs and simulations backed by laboratory tests and demonstrations at ORNL have shown the feasibility of detection of specified flaw properties in tubing welds in the SSME heat exchangers. The flaw signals using a specially designed probe and an existing ORNL multifrequency eddy-current instrument are robust and field interpretable. The probe and flexible cabling can be interfaced to existing drive systems at Rocketdyne to yield a practical working instrument for inspecting tubing welds in the field through existing tube ports with minimal inspection effort. Additional simulations indicate that an even better inspection with greater confidence could be achieved using pulsed eddy-current techniques that have recently been developed at ORNL. This system offers higher speed, lower cost and simpler operation with a computerized instrument now in the design stages.

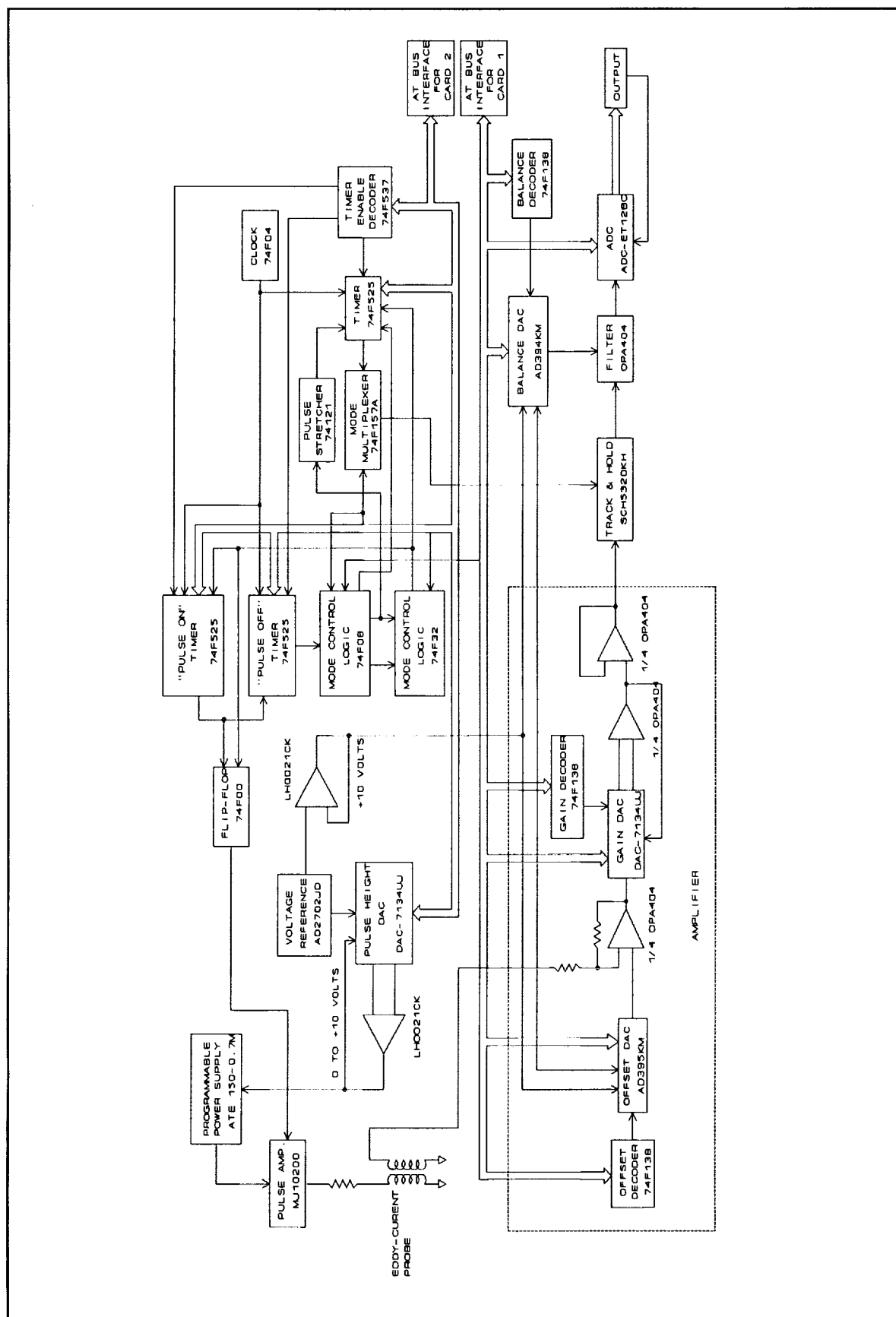


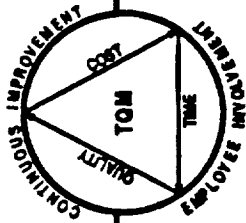
Figure 9 Block diagram of pulsed eddy-current instrument interfaced to a PC-AT bus

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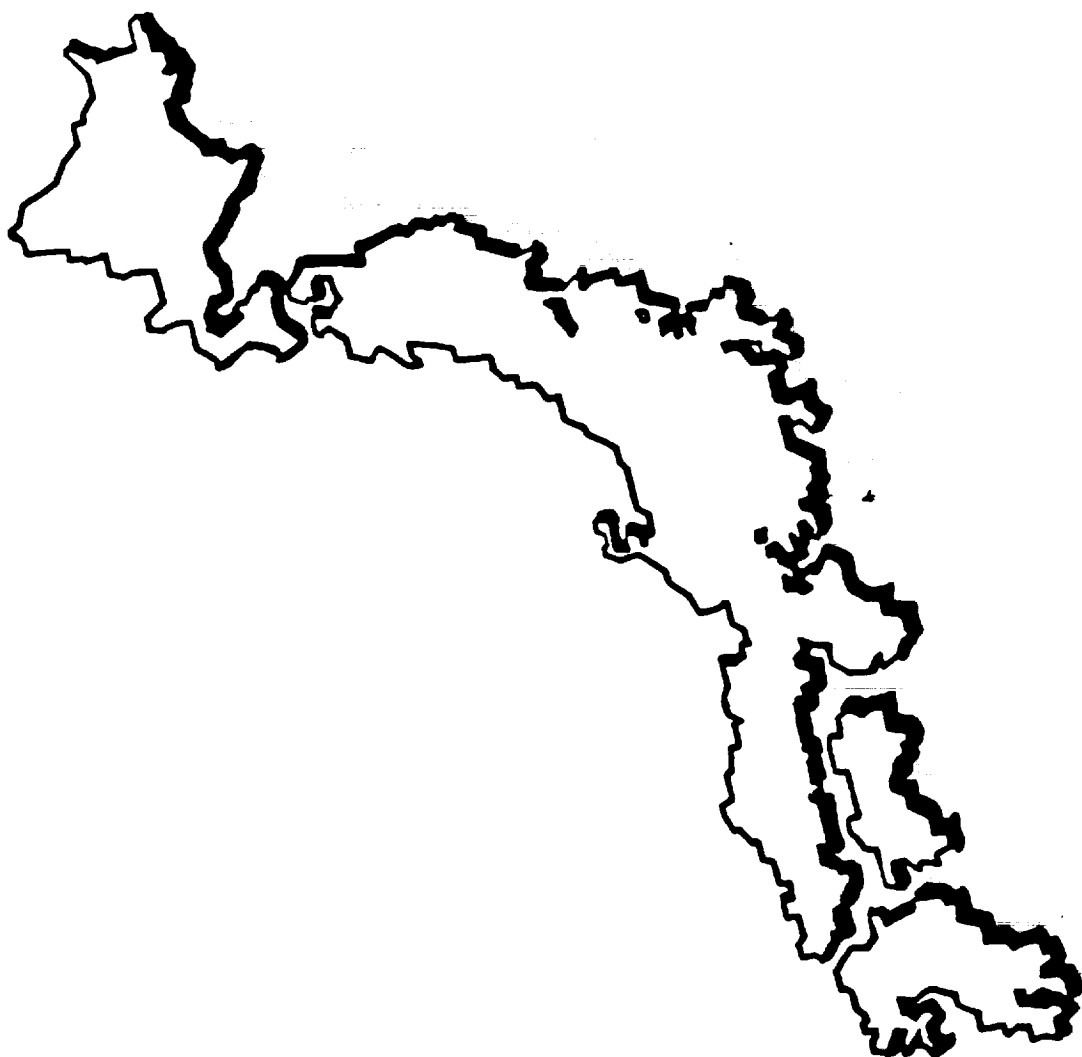
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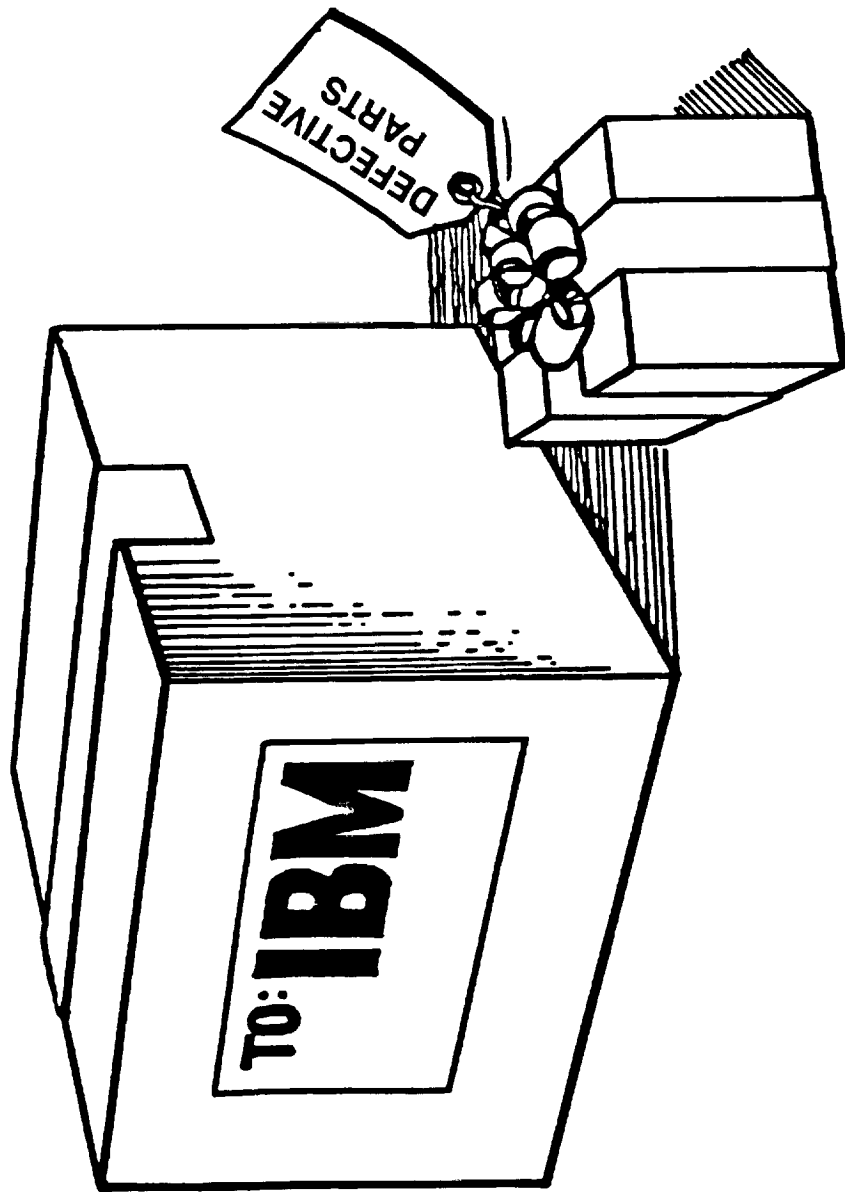
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NONDESTRUCTIVE EVALUATION (NDE) AND TOTAL QUALITY MANAGEMENT (TQM) FOR MISSILE SYSTEMS

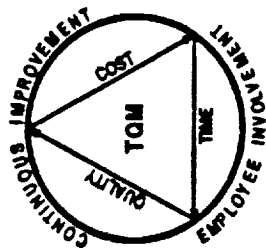
**NDE FOR AEROSPACE SYMPOSIUM
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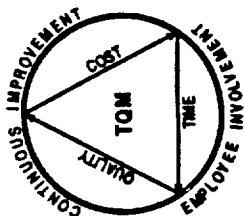


CONSUMER SATISFACTION INDEX (CSI) - CARS



MERCEDES-BENZ	159
TOYOTA	137
JAPANESE CARS OVERALL	115
GERMAN CARS OVERALL	110
FORD	107
CHRYSLER	91
GENERAL MOTORS	81
AMERICAN MOTORS	76

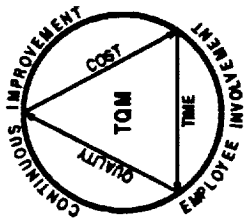
- SOURCES:**
1. THRIVING ON CHAOS BY TOM PETERS, 1986
 2. THE DEMING ROUTE TO QUALITY AND PRODUCTIVITY, W. SCHERKENBACH, 1988



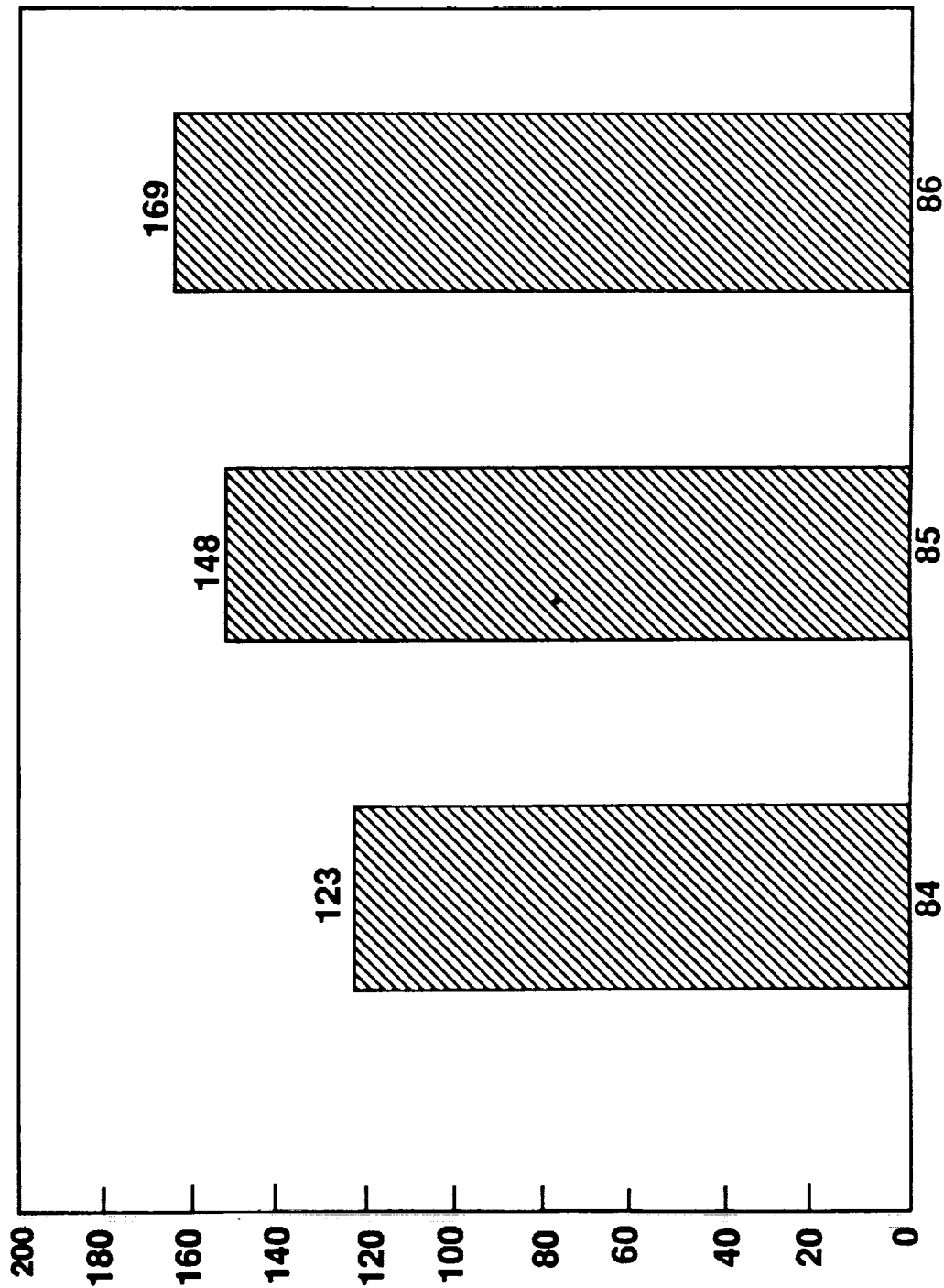
WORLDWIDE PRODUCTION

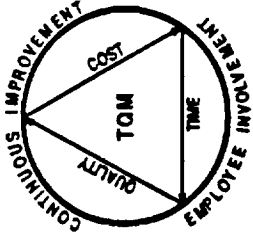
	<u>1960s</u>	<u>1988</u>
CARS	76%	24%
MACHINE TOOLS	100%	35%
TURNTABLES	90%	1%
COLOR TVs	90% (27 FIRMS)	10% (1 FIRM)

SOURCE : "LOSING THE FUTURE," NEWS SPECIAL
BY SANDY VANOCUR, NOV 1988.



TRADE DEFICITS (BILLIONS OF DOLLARS)



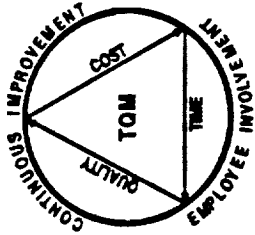


TQM - JAPANESE EMPHASIS

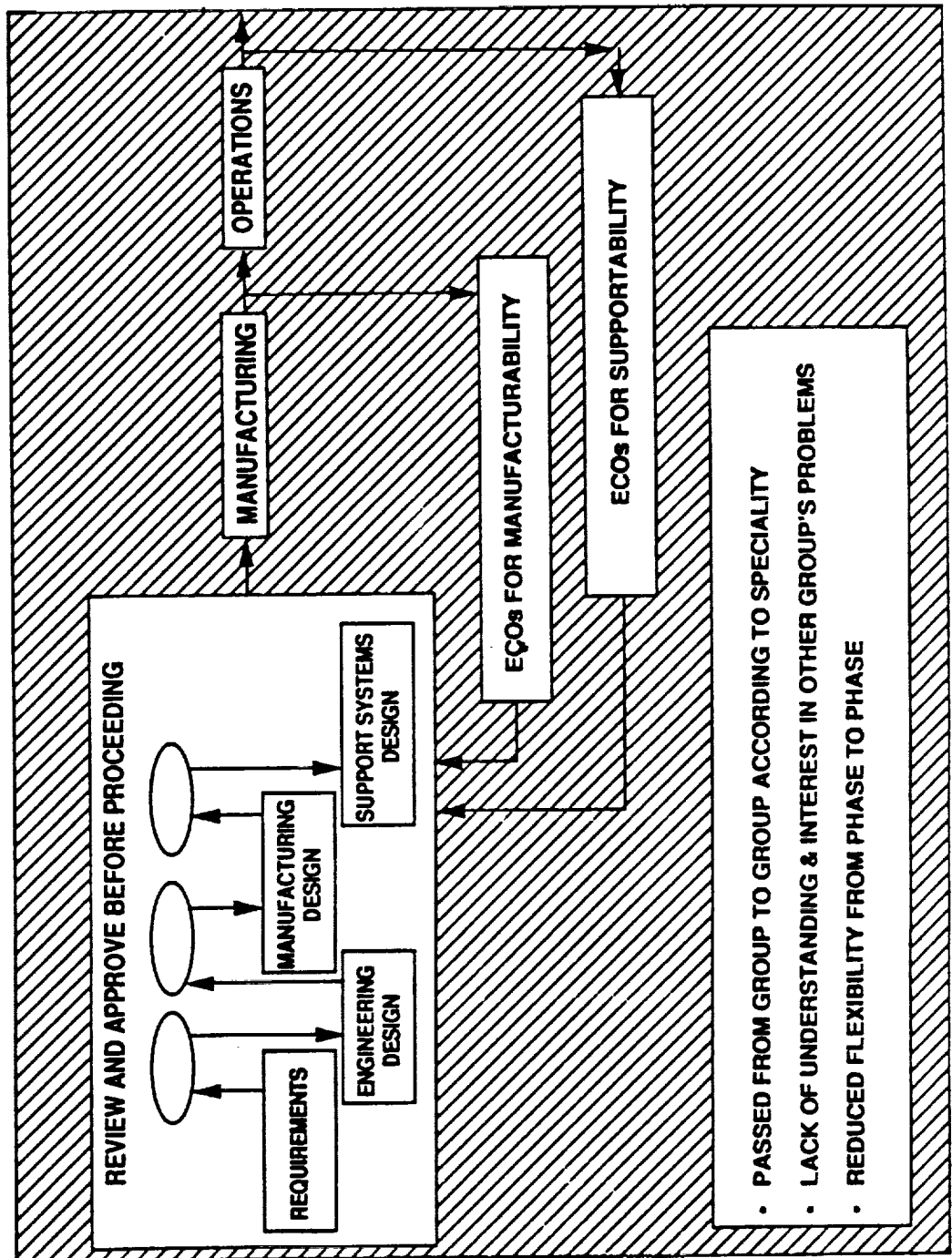
- JAPANESE HAVE BEEN PERFECTING THE TQM PROCESS FOR 40 YEARS (CONTINUOUS PROCESS IMPROVEMENT)
- JAPANESE TQM EMPHASIS IS BASED ON THE PRINCIPLE THAT HIGHER QUALITY RESULTS IN:
 - LOWER COST (LESS SCRAP AND REWORK)
 - SHORTER PRODUCT LEAD TIME (FEWER TEST FAILURES AND PROBLEMS, ALONG WITH HIGHER YIELDS)
 - BETTER PERFORMANCE (HIGHER RELIABILITY)

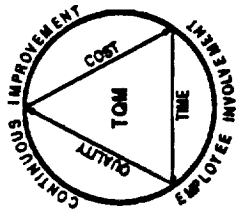
BOTTOM LINE:

INCREASED CUSTOMER SATISFACTION AND MARKET SHARE

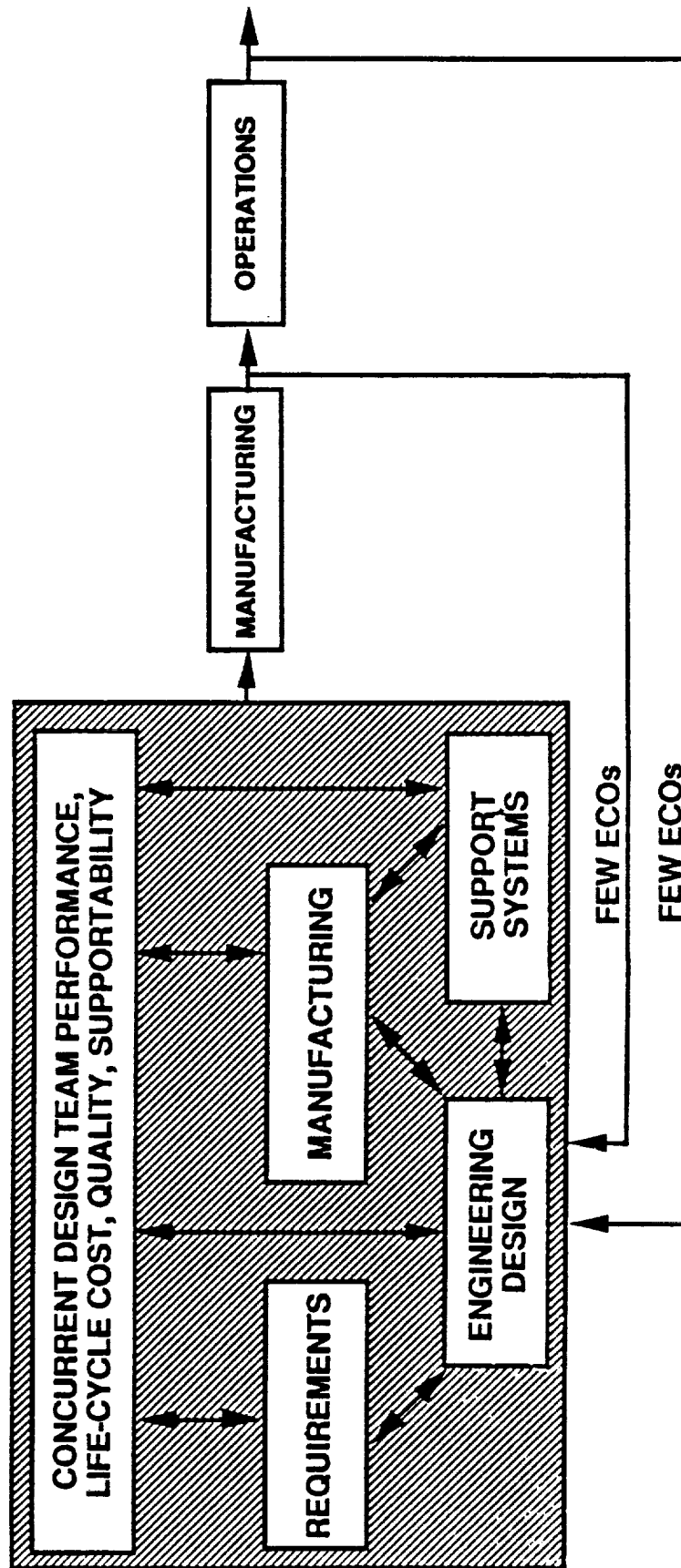


TYPICAL PHASED DEVELOPMENT

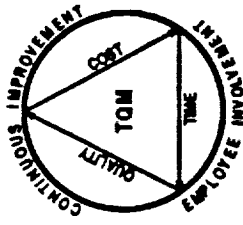




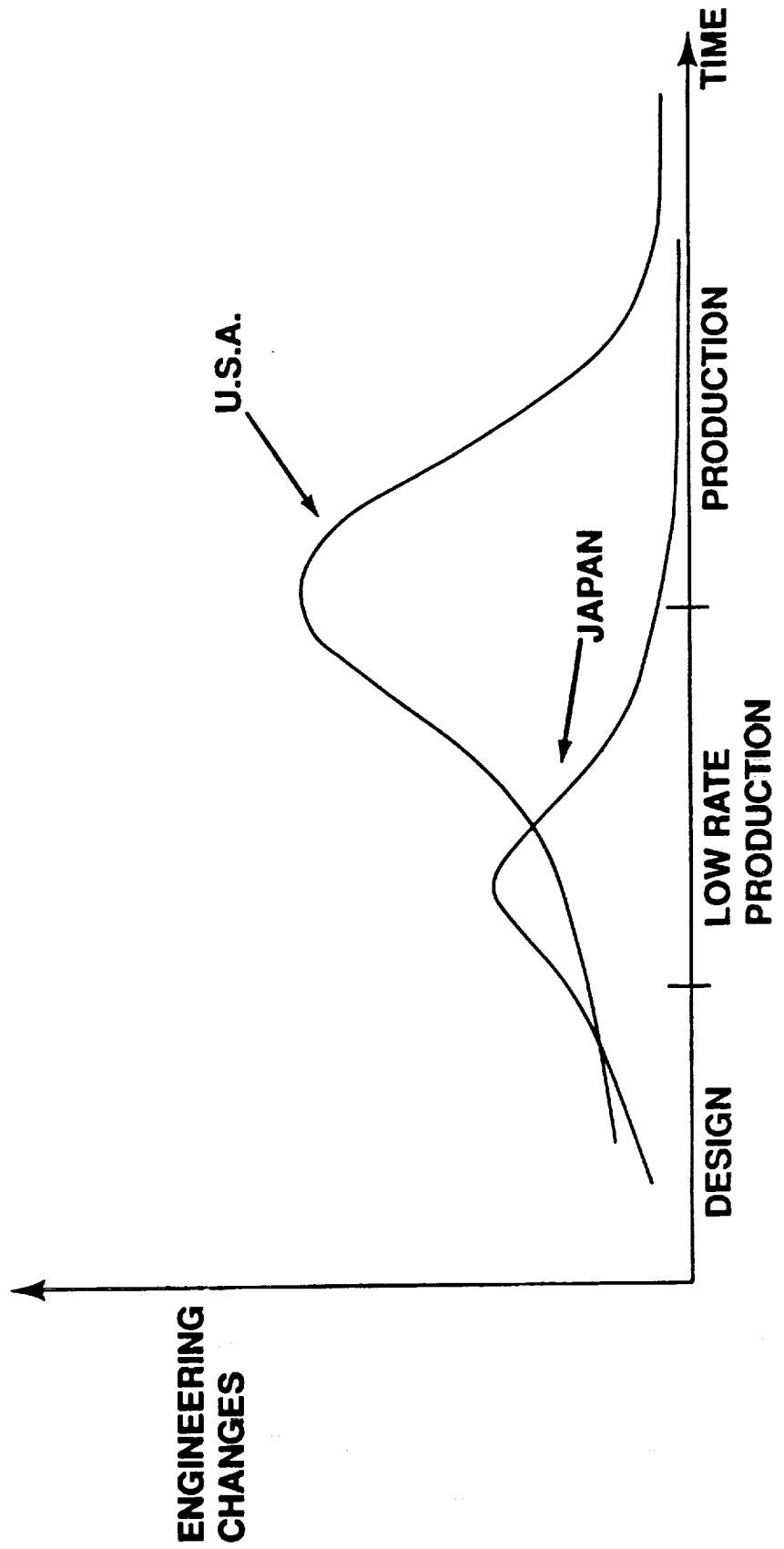
CONCURRENT ENGINEERING

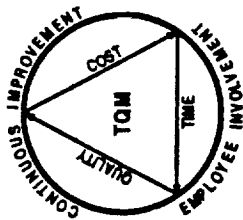


- "DESIGN QUALITY IN VS. INSPECT QUALITY IN"
- "GET IT RIGHT THE FIRST TIME"
- COMPRESSION OF DESIGN & DEVELOPMENT TIME
- LOWEST LIFE-CYCLE COSTS



NUMBER OF ENGINEERING CHANGES OVER PRODUCT LIFE CYCLE

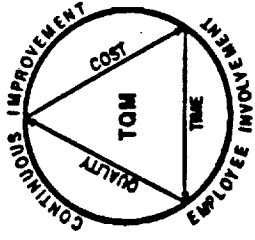




GUIDING PRINCIPLES FOR A TQM PROGRAM

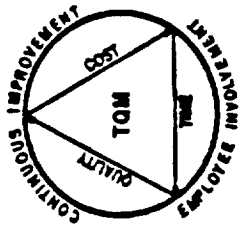
- QUALITY FIRST
- CUSTOMER SATISFACTION
- CONTINUOUS IMPROVEMENT
- MANAGEMENT COMMITMENT
- EMPLOYEE COMMITMENT
- SUPPLIER PARTICIPATION

DR. DEMING : WE MUST HAVE A PROFOUND KNOWLEDGE OF THE PROCESSES - - IN THE USA WE MAKE TOO MANY QUICK FIXES, BASED ON HUNCHES

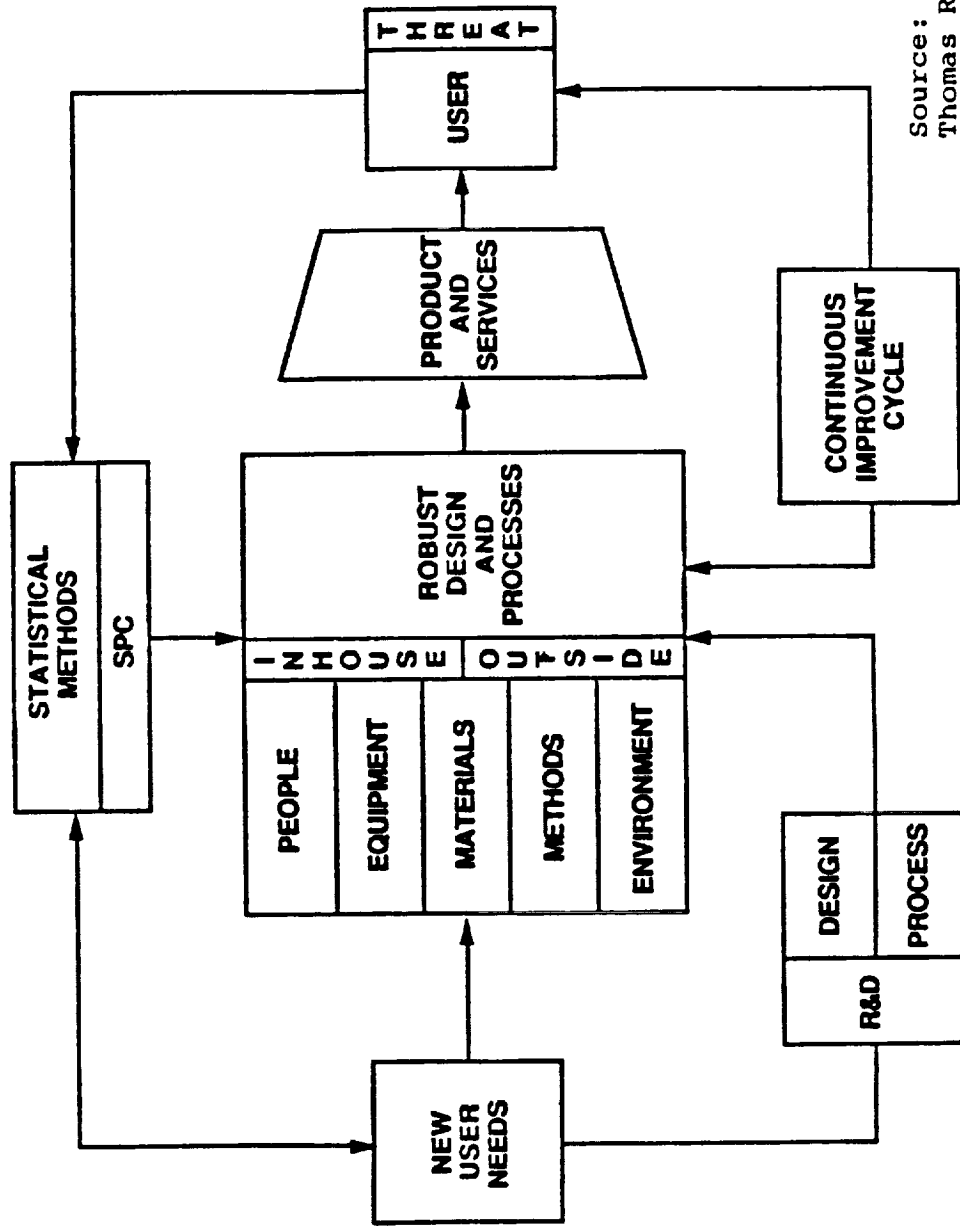


PROBLEM-SOLVING TOOLS

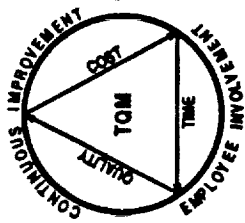
- PARETO DIAGRAMS
- ISHIKAWA (FISHBONE) DIAGRAMS
- HISTOGRAMS
- CONTROL CHARTS
- SCATTER PLOTS ;
- PROCESS FLOW DIAGRAMS
- PARAMETER OPTIMIZATION TECHNIQUES
 - TAGUCHI METHODS
 - STATISTICAL DESIGN OF EXPERIMENTS
- CHECK SHEETS
- NEW QUALITATIVE TECHNIQUES



TOTAL QUALITY MANAGEMENT (TQM) - DEFENSE INDUSTRY



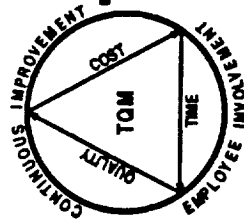
Source:
Thomas R. Stuelpnagel
National Defense, Nov 88



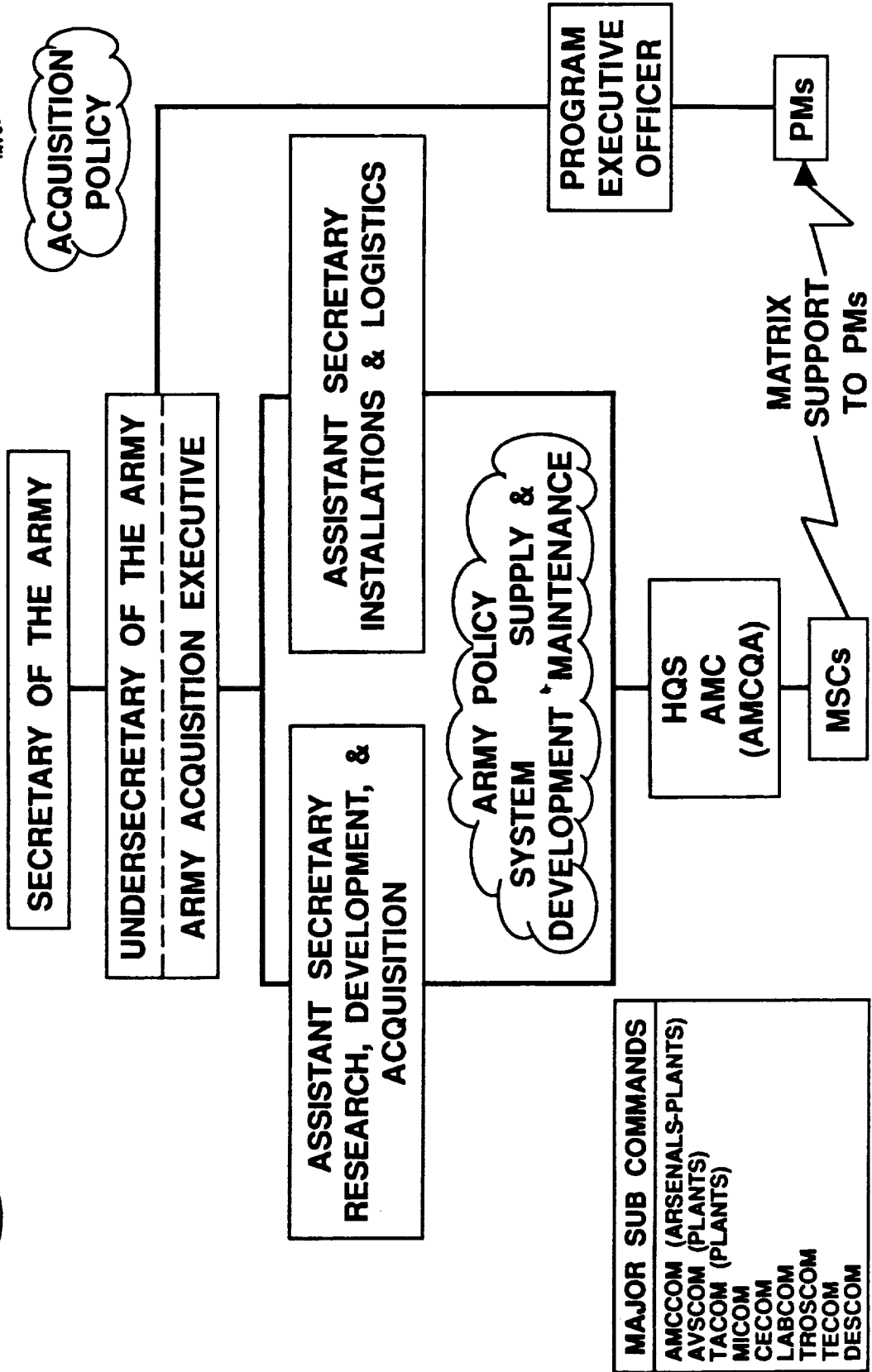
TQM

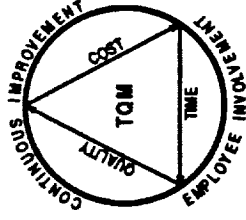
- **PARTICIPATIVE SENIOR MANAGEMENT PHILOSOPHY
EMPHASIZING QUALITY**
- **TOTAL LIFE CYCLE DESIGN PHILOSOPHY**
- **MULTI-LEVEL, CROSS-ORGANIZATIONAL LINKAGES TO
OPTIMIZE QUALITY**
- **CONTINUOUS IMPROVEMENT OF ALL PROCESSES,
INVOLVING EVERYONE**

**PLAN, DESIGN, BUILD AND MAINTAIN QUALITY IN:
“DOING RIGHT THINGS RIGHT THE FIRST TIME”**



ORGANIZATION

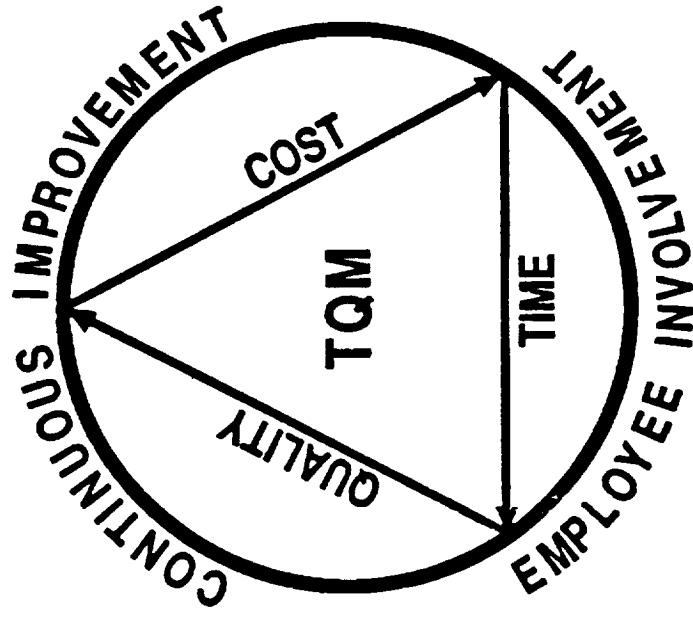




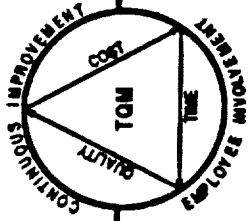
TOTAL QUALITY MANAGEMENT PAD'S MISSION

- **STRATEGY: CONTINUOUS QUALITY IMPROVEMENT PROCESS**
- **HIGHER LEVELS OF PERFORMANCE IN ALL AREAS OF RESPONSIBILITY**
- **PROVIDE USER SATISFACTION**
- **ASSURE MICOM PRODUCTS CONFORM TO CORRECTLY DEFINED TECHNICAL REQUIREMENTS**
- **ASSURE THAT QUALITY IS EMPHASIZED IN EVERY PHASE OF THE PRODUCT LIFE CYCLE**
- **INCREASE WAR-FIGHTING CAPABILITY**

TOTAL QUALITY MANAGEMENT (TQM)



THROUGH NONDESTRUCTIVE EVALUATION (NDE)

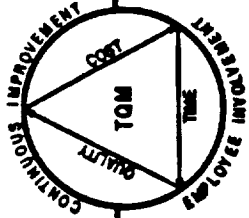


NDE A VITAL PART OF TQM

REASONS FOR EMPHASIS:

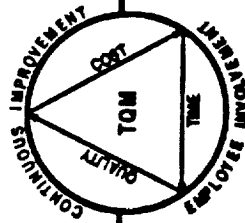
- **RAPIDLY INCREASING COST OF WEAPON SYSTEMS**
- **TECHNOLOGICAL CHANGES IN STRUCTURES AND PROPULSION SYSTEMS**
- **DEVELOPMENT OF ADVANCED, LIGHTWEIGHT, HI-STRENGTH MATERIALS**
 - **SUSCEPTIBLE TO SMALL DEFECTS, MFG FLAWS**
 - **REQUIRES DEVELOPMENT AND USE OF ADVANCED NDE METHODS**

- **NDE NECESSITY THROUGH ENTIRE LIFE CYCLE**
- **QUALITY ASSURANCE ORGANIZATIONS/NDE MUST:**
 - **PROVIDE DETECTION OF DEGRADED COMPONENTS**
 - **AND REMOVE BEFORE CATASTROPHIC FAILURE**



NDE A MAJOR AMC THRUST AREA

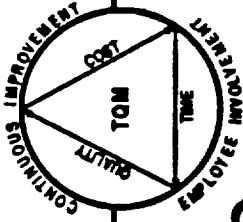
- **DESIGNATED BY AMC MANUFACTURING TECHNOLOGY STEERING GROUP MEETING AT AMC HDQTRS 6-7 DEC 88**
- **OTHER THRUST AREAS THAT REQUIRE USE OF NDE/NDT**
 - **SURFACE MOUNT SOLDERING TECHNOLOGY (SMT)**
 - **COMPOSITE MATERIALS PROCESSING**
 - **ENERGETIC MATERIALS (PROPELLANTS, PYROTECHNICS) MANUFACTURING**
 - **HEAVY PLATE WELDING**
 - **ADHESIVE BONDING**
 - **MACHINING**
- **GOALS OF THESE NDE THRUSTS AND THIS CONFERENCE ARE:**
 - **TO PROMOTE COOPERATION MICOM/NASA/INDUSTRY**
 - **TO GET ADVANCED NDE TECHNOLOGY ON THE FACTORY FLOOR**



MATERIALS TECHNOLOGY LABORATORY (MTL) (WATERTOWN, MA)

ARMY CENTER OF EXCELLENCE IN MANUFACTURING NDE

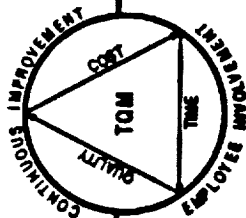
- **MANAGE NDE THRUST AREAS**
- **COORDINATE NDE TECHNOLOGY DEVELOPMENT**
 - **TECHNOLOGY DEVELOPED IN DOD, INDUSTRY OR ACADEMIA**
 - **APPLY TO ARMY PROBLEMS**
- **TEAMWORK:**
 - **MTL**
 - **SOUTHWEST RESEARCH INSTITUTE**
 - **JOHNS HOPKINS LABORATORY**
- **ACTION AREAS:**
 - **IDENTIFY R&D AREAS & COORDINATE RESEARCH**
 - **EVALUATE AND FUND PROJECT PROPOSALS**
 - **EVALUATE & DEMONSTRATE NEW EQUIPMENT & TECHNOLOGIES**
 - **SPONSOR SEMINARS & TECHNICAL TRAINING**
 - **TRANSFER NDE TECHNOLOGY INTO MANUFACTURING**



MICOM RESEARCH, DEVELOPMENT AND ENGINEERING CENTER (RDEC)

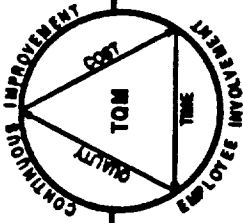
**SYSTEMS ENGINEERING & PRODUCTION DIRECTORATE (SEPD) NDE
INITIATIVES**

- **MANUFACTURING METHODS AND TECHNOLOGY (MM&T)**
- **MATERIALS TESTING TECHNOLOGY (MTT)**
 - AR 700-90, ARMY INDUSTRIAL PREPAREDNESS PROGRAM
 - MICOM REG. 70-32J, MM&T, MTT & MILITARY ADAPTATION OF COMMERCIAL ITEMS
- **"MANTEST", MICROCIRCUIT THERMAL SCREENING**
 - A MANUAL CHIP SCREENING SYSTEM
 - AVAILABLE FOR DEMONSTRATION
- **AUTOMATIC OPTICAL INSPECTION OF PRINTED WIRING BOARDS -
FY 89**
- **LASER DEVICE TO DETECT FLAWS/MICROCRACKING IN OPTICAL
FIBERS**
 - THROUGH INDUCED STRESS
 - IN PLANNING STAGE



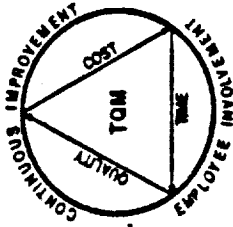
MICOM PRODUCT ASSURANCE DIRECTORATE NDE/NDT

- **RESPONSIBILITY FOR CERTIFICATION OF CRITICAL PROCESSES**
 - SOLDERING
 - WELDING
 - NDE/NDT
 - ADHESIVE BONDING
- **QUALITY AUDITS**
 - NDE/NDT CAPABILITIES, PROCESSES AT CONTRACTOR PLANTS AND ARMY DEPOTS
- **SOLDERING TECHNOLOGY & CERTIFICATION CENTER**
 - VANZETTI LASER INSPECTION SYSTEM
 - X-RAY INSPECTION SYSTEM
 - PROJECTED OPERATION LATTER PART FY 89
 - CONDUCT NDE STUDIES OF SOLDER JOINTS, PRINTED WIRING BOARDS, SURFACE MOUNT TECHNOLOGY (SMT)
 - SMT STUDY FY 89-90



MICOM PRODUCT ASSURANCE DIRECTORATE NDE/NDT (CONT)

- **NDE REQUIREMENTS IN QUALITY ASSURANCE
PROVISIONS (QAPs) FOR TECHNICAL DATA PACKAGES
(TDPs)**
- **HANDBOOK FOR NDE/NDT (25 VOLUMES)**
 - 20 METHODS
 - PREPARATION OF QAPs FOR TDPs
 - AVAILABLE HERE AT CONFERENCE
- **RELATED DISCIPLINES**
 - STATISTICAL PROCESS CONTROL (SPC)
 - SPECIAL INSPECTION EQUIPMENT (SIE)
 - ENVIRONMENTAL STRESS SCREENING (ESS)



RAM ENGINEERING AND SYSTEM ASSESSMENT

TQM RELATED ACHIEVEMENTS

RAM TESTING OF STOCKPILE - SHELF LIFE ASSESSMENTS

SYSTEM	INITIAL PREDICTION	CURRENT PREDICTION
REDEYE	3 YRS	23 YRS
HAWK MTR	5 YRS	20 YRS
TOW	5 YRS	20 YRS
SHILLELAGH	5 YRS	22 YRS
DRAGON	5 YRS	16 YRS

SYSTEM ASSESSMENT OF FIELDIED SYSTEMS

- MLRS PROBLEMS
- ENGINEERING CHANGES
- INCREASED MEANTIME BETWEEN FAILURES OVER 100%

• CONFIRMED RELIABILITY
• CONFIRMED SAFETY
• SAVED REPROCUREMENT/REBUILD COSTS

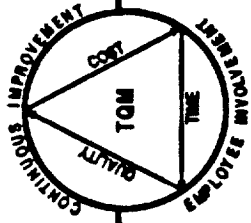
PATRIOT-5 TO 7
YEARS

\$2 BILLION
COST AVOIDANCE

INCREASED
COMBAT
CAPABILITY



QUALITY IMPACT OF NONDESTRUCTIVE EVALUATION



QUALITY

IS NOT JUST FREE --
IT PAYS

INDUSTRY

- LESS SCRAP/REWORK
- MORE COMPETITIVE
- GREATER PROFITS

CUSTOMER SATISFACTION

INCREASED

WAR-FIGHTING CAPABILITY

GOVERNMENT

- MORE FOR TAX DOLLARS
- SCHEDULES MET
- IMPROVED READINESS
- REDUCED SURVEILLANCE



SOLDIER

